The Association

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Engineering and Shipbuilding Draughtsmen.

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Design of Axially Loaded Reinforced Concrete Columns.

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By ANTHONY d'O SMITH,
Member American Society of Civil Engineers ;
American Concrete Institute.

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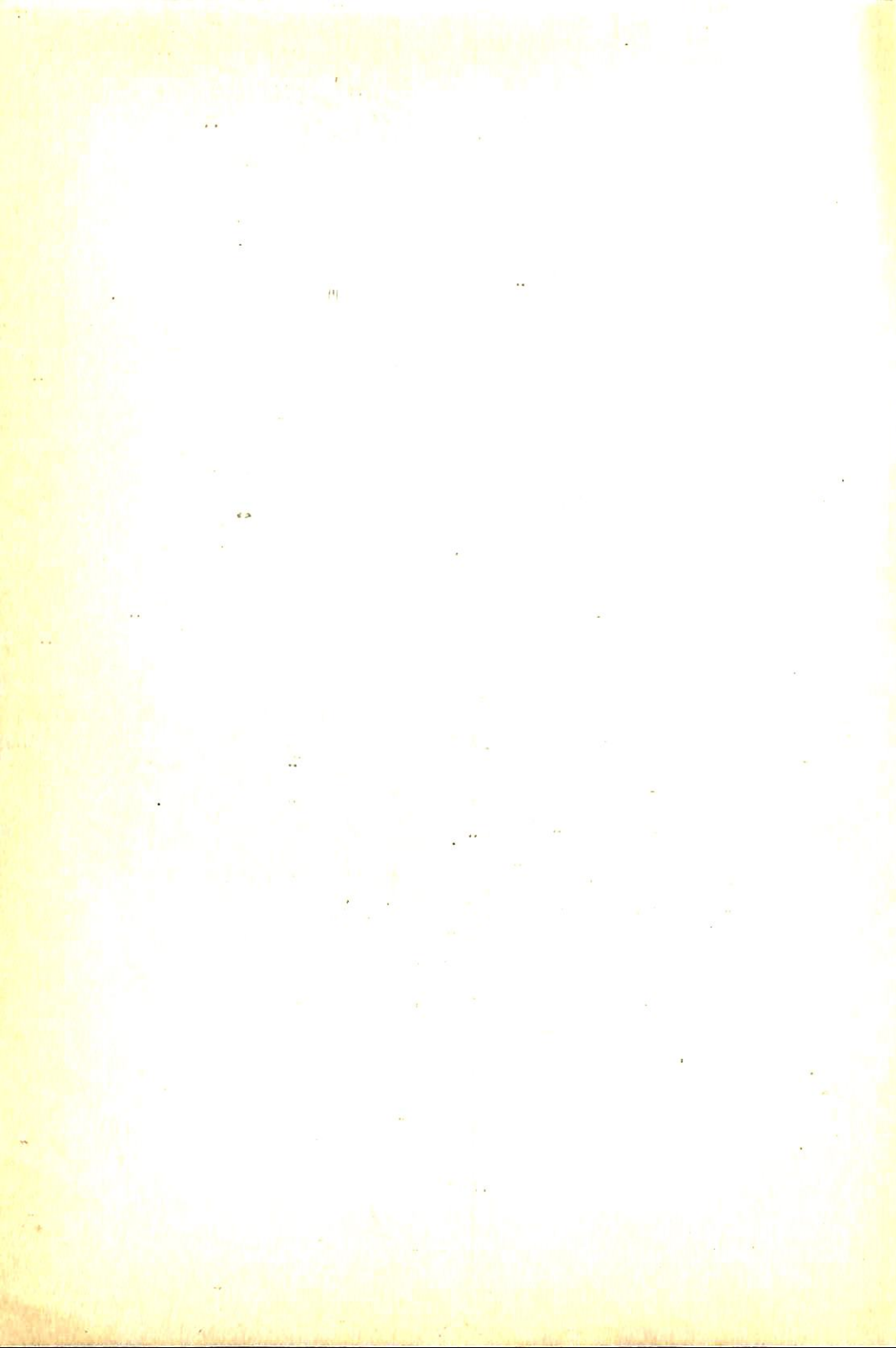
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DESIGN OF AXIALLY LOADED REINFORCED CONCRETE COLUMNS.

ULTIMATE LOAD METHOD.

The Code of Practice C.P. 114 (1948) allows reinforced concrete columns to be designed by the ultimate load or plastic load method evolved from investigations and tests carried out to failure. It disregards the modular ratio and asserts that the unit stresses are proportional to their compressive strengths obtained from the concrete crushing strength in long prisms or concrete test cylinders and the yield point strength of the steel.

Basic Formula para. 312 (ii) is :—

$$P = cA + c_1 A_c$$

Where P = Axial load permissible on a short column.
A_c = Cross-sectional area of longitudinal steel in sq. in.
A = The cross-sectional area of concrete minus area of column bars in sq. in.
c = Permissible stress in concrete in direct compression.
c_1 = Permissible compression stress for column bars.

For round and square mild steel bars c_1 = 18,000 lb. per sq. in.

For square twisted and "Tentor" bars c_1 = 20,000 lb. per sq. in.

On simplifying basic formula by substituting A_g, the gross area of column in sq. in.

$$A_g = A_c + A$$
$$\text{Whence } A = A_g - A_c$$

and using mild steel with normal grade concrete then :—

$$
\begin{aligned}
\text{For } 1:2\ :4 \text{ mix } .....P &= 760\ (A_g - A_c) + 18000\ A_c \\
&= 760\ A_g + 17240\ A_c \ ... \qquad ... \ (a) \\
\text{For } 1:1\tfrac{1}{2}:3 \text{ mix } .....P &= 950\ A_g + 17050\ A_c \ ... \qquad ... \ (b) \\
\text{For } 1:1\ :2 \text{ mix } .....P &= 1140\ A_g + 16860\ A_c \ ... \qquad ... \ (c)
\end{aligned}
$$

Using cold twisted steel.

$$
\begin{aligned}
\text{For } 1:2\ :4 \text{ mix } .....P &= 760\ A_g + 19240\ A_c \ ... \qquad ... \ (d) \\
\text{For } 1:1\tfrac{1}{2}:3 \text{ mix } .....P &= 950\ A_g + 19050\ A_c \ ... \qquad ... \ (e) \\
\text{For } 1:1\ :2 \text{ mix } .....P &= 1140\ A_g + 18860\ A_c \ ... \qquad ... \ (f)
\end{aligned}
$$

The capacity for a concentrically loaded column according to formulae $(a-f)$ from which the design tables given in this book are computed, consists basically of two elements :—

(1)   The load carried by the concrete, and
(2)   the load carried by the reinforcement.

Tables 1-5 give the safe carrying capacity in kips (1000 lb. units) for tied reinforced concrete short columns for which the *unsupported length is not greater than fifteen times the least dimension.* The allowable loads are calculated using the maximum permissible stresses specified in Clause 303 (*a*) and (*b*), and three loads are given for each column size by using normal grade concretes of 3000, 3750 and 4500 lb. per sq. in. crushing strength, the mix being identified in the heading of the tables by the direct compression stress in lb. per sq. in.

The general design procedure is :—

(1)   Enter Table 1 for the size of column being designed, decide on a mix and select the load carried by the concrete.

(2)   Subtract the load on the concrete from the total load to determine the load which must be carried by the reinforcement.

(3)   Enter that part of Tables 2-5 giving the number and size of bars under the concrete mix used, and select bars required to carry the load taken by the reinforcement. (Use appropriate table for either round or square mild steel, square twisted or "Tentor" bars).

It will be noted that the Code fixes the minimum amount of longitudinal reinforcement at 0·8% of the cross-sectional area of the column and maximum amount at 8%. These limits are indicated in Table 1 (calculated for mild steel) under the sections headed Min. and Max. load on column. This gives a range which is ample for all practical columns and the total load carried by the column being designed should fall between the limits shown.

Example :—assume column size 18″ × 18″

Column load P   ...   .   350 kips

Load on concrete from Table 1 for 18″ square
     column 1 : 2 : 4 mix   ...   .   246 kips

Remainder of load to be carried by longitudinal bars,   104 kips

Enter Table 2 under that section computed for a 1 : 2 : 4 mix, select eight 1″ round mild steel bars load 108 kips ; the value 350 kips is between the maximum and minimum load, therefore the column size assumed is satisfactory.

From the example given and continued use of Tables 1-5, the designer will notice that the values given in Part 1, Table 1, under the section headed "Load on Concrete Only" together with Part 2, Tables 2-5, Load on Bars, form the two basic elements of the column formulae (*a-f*). The sum of the data provided in these

two sections will give the safe load for all the range of indicated column sizes using any desired number of vertical bars.

Part 2 which consists of Tables 2-5 is calculated for four types of reinforcing bars in common use and each of these tables is arranged in three sections for 1 : 2 : 4, 1 : 1½ : 3 and 1 : 1 : 2 mixes respectively.   Care should be taken when selecting a column size designed for a direct compression stress of say 950 lb. per sq. in. that the bars are, in turn, selected from that section of the bar tables calculated and tabulated to correspond with the chosen concrete stress.

The sizes of columns indicated in Table 1 cover a wide range and include those adopted in British Standard 2539, 1954, "Preferred Dimensions of Reinforced Concrete Structural Members."   When designing buildings outside the London area the Model Byelaws Series IV Buildings, 1952, give the minimum overall size of column to be used for various periods of fire resistance.   These fireproofing requirements must be carefully studied when submitting plans to local authorities for byelaw approval.

Table 7 (Calculated for Mild Steel).

This Table gives the safe axial load on square tied short columns reinforced with from 1 to 8 per cent. of mild steel using the three grades of concrete indicated for each column size.

From 1% to 4% longitudinal steel is commonly used, this being dependent upon the number of bars that can be placed within the cross-section to prevent over crowding of the bars at a lapped splice.   The minimum size bar permitted is ½" diameter and the maximum 2" diameter, the area of the chosen percentage of steel can be converted into number of bars by the use of Table 6.

The axial capacity of a round tied column can be approximated by taking 82% of the capacity of a square tied column with side equal to the diameter and with the same number of vertical bars.

The values given in Table 7 for square tied columns may easily be extended to include rectangular tied columns as follows :—

Suppose the load to be carried is 200 kips and that the side of the column is limited to 12 inches.   A 12" × 12" column with 1% steel 1 : 2 : 4 mix has an allowable load value of 134 kips.   Set 134 on the slide rule and multiply by a number which will give 200, in this case 1·5.   Therefore, the long side of the column should be 1·5 × 12 or 18 inches.   Use a 12" × 18" section reinforced with 1% steel amounting to 2·16 sq. in. and from Table 6 select 4-⅞" mild steel rounds area 2·40 sq. in.

The scope of the tables lies in the fact that the design of columns by the Code method can be reduced to two simple operations, the load on the concrete plus the load on the bars. The designer can quickly see the limitations and possibilities of the various sections, and select preliminary sizes before analysis of building frames by moment distribution methods.

If it is found necessary to amend contract drawings owing to a certain type or size of bar being more readily available from stock it will be found possible to rapidly redesign the reinforcement with the aid of Tables 2-5.

For the experienced engineer who can quickly convert a column moment into an equivalent axial load the tables offer further possibilities and permit the design of columns to be arranged in simple schedules.

Structural engineers will find the tables a quick and rapid tool for office usage, and municipal engineers will find the tables helpful in checking calculations and plans deposited under building byelaws.

TIED COLUMNS. C.P. 114 (1948).
SAFE AXIAL LOADS IN KIPS (1,000 lbs.).
Mild Steel. $C_1 = 18,000$ p.s.i.
PART I.
TABLE 1.

Column Size in.		Gross Area Ag	Minimum Load on Column with 0·8% Steel			Maximum Load on Column with 8% Steel			Load on Concrete Only		
			Direct Compression Stress								
			760	950	1140	760	950	1140	760Ag	950Ag	1140Ag
5	8	40	36	43	51	85	92	99	30	38	45
	9	45	40	48	57	96	104	112	34	42	51
	10	50	44	54	63	107	115	124	38	47	57
	12	60	53	65	76	128	138	149	45	57	68
	14	70	62	76	89	149	162	174	53	66	79
	15	75	67	81	95	160	173	186	57	71	85
	16	80	71	87	102	171	185	199	60	76	91
	18	90	80	97	114	192	208	224	68	85	102
	20	100	89	108	127	214	231	248	76	95	114
	21	105	94	114	133	224	243	261	79	99	119
	22	110	98	119	140	235	254	273	83	104	125
	24	120	107	130	153	256	277	298	91	114	136
	27	135	121	146	172	288	312	336	102	128	154
	30	150	134	163	191	320	347	373	114	142	171
6	6	36	32	39	46	77	83	89	27	34	41
	7½	45	40	48	57	96	104	112	34	42	51
	8	48	43	52	61	102	111	119	36	45	54
	9	54	48	58	68	115	125	134	41	51	61
	10	60	53	65	76	128	138	149	45	57	68
	10½	63	56	68	80	134	145	156	47	59	71
	12	72	64	78	91	154	166	179	54	68	82
	13½	81	72	88	103	173	187	201	61	77	92
	14	84	75	91	107	179	194	209	63	79	95
	15	90	80	97	114	192	208	224	68	85	102
	16	96	86	104	122	205	222	239	73	91	109
	18	108	97	117	137	231	250	268	82	102	123
	20	120	107	130	153	256	277	298	91	114	136
	21	126	113	136	160	269	291	313	95	119	143
	22	132	118	143	168	282	305	328	100	125	150
	24	144	129	156	183	308	333	358	109	136	164

Table 1—*continued.*

Column Size in.		Gross Area Ag	Minimum Load on Column with 0·8% Steel			Maximum Load on Column with 8% Steel			Load on Concrete Only		
			Direct Compression Stress								
			760	950	1140	760	950	1140	760Ag	950Ag	1140Ag
6	27	162	145	176	206	346	374	403	123	154	184
	30	180	161	195	229	385	416	448	136	171	205
7	7	49	44	53	62	104	113	122	37	46	55
	8	56	50	60	71	119	129	139	42	53	63
	9	63	56	68	80	134	145	156	47	59	71
	10	70	62	76	89	149	162	174	53	66	79
	12	84	75	91	107	179	194	209	63	79	95
	14	98	88	106	125	209	226	244	74	93	111
	15	105	94	114	133	224	243	261	79	99	119
	16	112	100	121	142	239	259	278	85	106	127
	18	126	113	136	160	269	291	313	95	119	143
	20	140	125	152	178	299	324	348	106	133	159
	21	147	132	159	187	314	340	365	111	139	167
	22	154	138	167	196	329	356	383	117	146	175
	24	168	150	182	214	359	388	418	127	159	191
	27	189	169	205	241	404	437	470	143	179	215
	30	210	188	228	267	449	486	522	159	199	239
7½	6	45	40	48	57	96	104	112	34	42	51
	7½	56·25	50	61	71	120	130	140	42	53	64
	9	67·5	60	73	86	144	156	168	51	64	77
	10½	78·75	70	85	100	168	182	196	59	74	89
	12	90	80	97	114	192	208	224	68	85	102
	13½	101·25	91	110	129	216	234	252	77	96	115
	15	112·5	101	122	143	240	260	280	85	106	128
	18	135	121	146	172	288	312	336	102	128	154
	21	157·5	141	171	200	337	364	392	119	149	179
	24	180	161	195	229	385	416	448	136	171	205
	27	202·5	181	220	258	433	468	504	154	192	230
	30	225	202	244	286	481	520	560	171	213	256
8	8	64	57	69	81	137	148	159	48	60	73

Table 1—*continued.*

Column Size in.		Gross Area Ag	Minimum Load on Column with 0·8% Steel			Maximum Load on Column with 8% Steel			Load on CONCRETE ONLY		
			Direct Compression Stress								
			760	950	1140	760	950	1140	760Ag	950Ag	1140Ag
8	12	96	86	104	122	205	222	239	73	91	109
	14	112	100	121	142	239	259	278	85	106	127
	15	120	107	130	153	256	277	298	91	114	136
	16	128	115	139	163	273	296	318	97	121	146
	18	144	129	156	183	308	333	358	109	136	164
	20	160	143	173	204	342	370	398	121	152	182
	21	168	150	182	214	359	388	418	127	159	191
	22	176	158	191	224	376	407	438	133	167	200
	24	192	172	208	244	410	444	477	146	182	218
	27	216	194	234	275	462	499	537	164	205	246
	30	240	215	260	306	513	555	597	182	228	273
9	6	54	48	58	68	115	125	134	41	51	61
	7½	67·5	60	73	86	144	156	168	51	64	77
	8	72	64	78	91	154	166	179	54	68	82
	9	81	72	88	103	173	187	201	61	77	92
	10	90	80	97	114	192	208	224	68	85	102
	10½	94·5	84	102	120	202	218	235	71	89	107
	11	99	88	107	126	211	229	246	75	94	112
	12	108	97	117	137	231	250	268	82	102	123
	13½	121·5	109	132	155	260	281	302	92	115	138
	14	126	113	136	160	269	291	313	95	119	143
	15	135	121	146	172	288	312	336	102	128	154
	16	144	129	156	183	308	333	358	109	136	164
	18	162	145	176	206	346	374	403	123	154	184
	20	180	161	195	229	385	416	448	136	171	205
	21	189	169	205	241	404	437	470	143	179	215
	22	198	177	215	252	423	458	492	150	188	225
	24	216	194	234	275	462	499	537	164	205	246
	27	243	218	264	309	519	562	604	184	230	277
	30	270	242	293	344	577	624	672	205	256	307

Table 1—*continued*.

Column Size in.		Gross Area Ag	Minimum Load on Column with 0·8% Steel			Maximum Load on Column with 8% Steel			Load on Concrete Only		
			Direct Compression Stress								
			760	950	1140	760	950	1140	760Ag	950Ag	1140Ag
10	10	100	89	108	127	214	231	248	76	95	114
	12	120	107	130	153	256	277	298	91	114	136
	14	140	125	152	178	299	324	348	106	133	159
	15	150	134	163	191	320	347	373	114	142	171
	16	160	143	173	204	342	370	398	121	152	182
	18	180	161	195	229	385	416	448	136	171	205
	20	200	179	217	255	427	462	497	152	190	228
	21	210	188	228	267	449	486	522	159	199	239
	22	220	197	239	280	470	509	547	167	209·	250
	24	240	215	260	306	513	555	597	182	228	273
	27	270	242	293	344	577	624	672	205	256	307
	30	300	269	326	382	641	694	746	228	285	342
10½	6	63	56	68	80	134	145	156	47	59	71
	7½	78·75	70	85	100	168	182	196	59	74	89
	9	94·5	84	102	120	202	218	235	71	89	107
	10½	110·25	99	119	140	235	255	274	83	104	125
	12	126	113	136	160	269	291	313	95	119	143
	13½	141·75	127	154	180	303	328	352	107	134	161
	15	157·5	141	171	200	337	364	392	119	149	179
	18	189	169	205	241	404	437	470	143	179	215
	21	220·5	198	239	281	471	510	548	167	209	251
	24	252	226	273	321	539	583	627	191	239	287
	27	283·5	254	308	361	606	656	705	215	269	323
	30	315	282	342	401	673	729	784	239	299	359
11	5	55	49	59	70	117	127	136	41	52	62
	6	66	59	71	84	141	152	164	50	62	75
	7	77	69	83	98	164	178	191	58	73	87
	7½	82·5	74	89	105	176	191	205	62	78	94
	8	88	79	95	112	188	203	219	66	83	100
	9	99	88	107	126	211	229	246	75	94	112

Table 1—*continued*.

Column Size in.		Gross Area Ag	Minimum Load on Column with 0·8% Steel			Maximum Load on Column with 8% Steel			Load on Concrete Only		
			Direct Compression Stress								
			760	950	1140	760	950	1140	760Ag	950Ag	1140Ag
11	10	110	98	119	140	235	254	273	83	104	125
	10½	115·5	103	125	147	247	267	287	87	109	131
	11	121	108	131	154	258	280	301	92	115	138
	12	132	118	143	168	282	305	328	100	125	150
	13	143	128	155	182	306	331	355	108	135	163
	13½	148·5	133	162	189	317	343	369	112	141	169
	14	154	138	167	196	329	356	383	117	146	175
	15	165	148	179	210	353	381	410	125	156	188
	16	176	158	191	224	376	407	438	133	167	200
	18	198	177	215	252	423	458	492	150	188	225
	20	220	197	239	280	470	509	547	167	209	250
	21	231	207	251	294	494	534	575	175	219	263
	22	242	217	263	308	517	560	602	184	230	275
	24	264	237	286	336	564	610	657	200	250	301
	27	297	266	322	378	635	687	739	225	282	338
	30	330	296	358	420	706	763	821	250	313	376
12	6	72	64	78	91	154	166	179	54	68	82
	7½	90	80	97	114	192	208	224	68	85	102
	9	108	97	117	137	231	250	268	82	102	123
	10½	126	113	136	160	269	291	313	95	119	143
	12	144	129	156	183	308	333	358	109	136	164
	13½	162	145	176	206	346	374	403	123	154	184
	14	168	150	182	214	359	388	418	127	159	191
	15	180	161	195	229	385	416	448	136	171	205
	16	192	172	208	244	410	444	477	146	182	218
	18	216	194	234	275	462	499	537	164	205	246
	20	240	215	260	306	513	555	597	182	228	273
	21	252	226	273	321	539	583	627	191	239	287
	22	264	237	286	336	564	610	657	200	250	301
	24	288	258	312	367	616	666	716	218	273	328
	27	324	291	352	413	693	749	806	246	307	369

Table 1—*continued*.

Column Size in.		Gross Area Ag	MINIMUM Load on Column with 0·8% Steel			MAXIMUM Load on Column with 8% Steel			Load on CONCRETE ONLY		
			Direct Compression Stress								
			760	950	1140	760	950	1140	760Ag	950Ag	1140Ag
12	30	360	323	391	459	770	833	896	273	342	410
13	9	117	105	127	149	250	270	291	89	111	133
	12	156	140	169	198	333	361	388	118	148	177
	13	169	151	183	215	361	391	420	128	160	192
	15	195	175	211	248	417	451	485	148	185	222
	18	234	210	254	298	500	541	582	177	222	266
	21	273	245	296	348	584	631	679	207	259	311
	24	312	280	339	397	667	722	776	237	296	355
	27	351	315	381	447	750	812	873	266	333	400
	30	390	350	423	497	834	902	970	296	370	444
13½	5	67·5	60	73	86	144	156	168	51	64	77
	6	81	72	88	103	173	187	201	61	77	92
	7	94·5	84	102	120	202	218	235	71	89	107
	7½	101·25	91	110	129	216	234	252	77	96	115
	8	108	97	117	137	231	250	268	82	102	123
	9	121·5	109	132	155	260	281	302	92	115	138
	10	135	121	146	172	288	312	336	102	128	154
	10½	141·75	127	154	180	303	328	352	107	134	161
	11	148·5	133	162	189	317	343	369	112	141	169
	12	162	145	176	206	346	374	403	123	154	184
	13	175·5	157	190	223	375	406	436	133	166	200
	13½	182·25	163	198	232	389	421	453	138	173	207
	14	189	169	205	241	404	437	470	143	179	215
	15	202·5	181	220	258	433	468	504	154	192	230
	18	243	218	264	309	519	562	604	184	230	277
	21	283·5	254	308	361	606	656	705	215	269	323
	24	324	291	352	413	693	749	806	246	307	369
	27	364·5	327	396	464	779	843	907	277	346	415
	30	405	363	440	516	866	937	1008	307	384	461
14	9	126	113	136	160	269	291	313	95	119	143
	12	168	150	182	214	359	388	418	127	159	191

Table 1—*continued.*

Column Size in.		Gross Area Ag	Minimum Load on Column with 0·8% Steel			Maximum Load on Column with 8% Steel			Load on Concrete Only		
			Direct Compression Stress								
			760	950	1140	760	950	1140	760 Ag	950 Ag	1140 Ag
	14	196	176	213	249	419	453	487	149	186	223
	15	210	188	228	267	449	486	522	159	199	239
	16	224	201	243	285	479	518	557	170	212	255
	18	252	226	273	321	539	583	627	191	239	287
14	20	280	251	304	357	599	648	696	212	266	319
	21	294	264	319	374	629	680	731	223	279	335
	22	308	276	334	392	658	712	766	234	292	351
	24	336	301	365	428	718	777	836	255	319	383
	27	378	339	410	482	808	874	940	287	359	431
	30	420	377	451	535	898	926	1045	319	399	478
	6	90	80	97	114	192	208	224	68	85	102
	7½	112·5	101	122	143	240	260	280	85	106	128
	9	135	121	146	172	288	312	336	102	128	154
	10½	157·5	141	171	200	337	364	392	119	149	179
	12	180	161	195	229	385	416	448	136	171	205
	13½	202·5	181	220	258	433	468	504	154	192	230
15	15	225	202	244	286	481	520	560	171	213	256
	18	270	242	293	344	577	624	672	205	256	307
	21	315	282	342	401	673	729	784	239	299	359
	24	360	323	391	459	770	833	896	273	342	410
	27	405	363	440	516	866	937	1008	307	384	461
	30	450	404	488	573	962	1041	1120	342	427	513
	16	256	229	278	326	547	592	637	194	243	291
	18	288	258	312	367	616	666	716	218	273	328
16	20	320	287	347	408	684	740	796	243	304	364
	22	352	316	382	448	753	814	876	267	334	401
	24	384	344	417	489	821	888	955	291	364	437
17	17	289	259	314	368	618	668	719	219	274	329
18	18	324	291	352	413	693	749	806	246	307	369
	20	360	323	391	459	770	833	896	273	342	410

Table 1—*continued*.

Column Size in.		Gross Area Ag	Minimum Load on Column with 0·8% Steel			Maximum Load on Column with 8% Steel			Load on Concrete Only		
			Direct Compression Stress								
			760	950	1140	760	950	1140	760 Ag	950 Ag	1140 Ag
	22	396	355	430	504	847	916	985	301	376	451
18	24	432	388	469	550	924	999	1075	328	410	492
	26	468	420	508	596	1001	1083	1164	355	444	533
19	19	361	324	392	460	772	835	898	274	343	411
	20	400	359	434	510	855	925	995	304	380	456
	22	440	395	478	561	941	1018	1095	334	418	501
20	24	480	431	521	612	1026	1110	1194	364	456	547
	26	520	467	565	663	1112	1203	1294	395	494	592
	28	560	502	608	714	1198	1295	1393	425	532	638
21	21	441	396	479	562	943	1020	1097	335	419	502
	22	484	434	525	617	1035	1120	1204	367	459	551
22	24	528	474	573	673	1129	1221	1314	401	501	602
	26	572	513	621	729	1223	1323	1423	434	543	652
	28	616	553	669	785	1317	1425	1533	468	585	702
23	23	529	475	574	674	1131	1224	1316	402	502	603
	24	576	517	625	734	1232	1332	1433	437	547	656
24	26	624	560	678	795	1334	1444	1553	474	592	711
	28	672	603	730	856	1437	1555	1672	510	638	766
25	25	625	561	679	796	1337	1446	1555	475	593	712
26	26	676	607	734	861	1446	1564	1682	513	642	770
	28	728	653	790	928	1557	1684	1811	553	691	830
27	27	729	654	792	929	1559	1687	1814	554	692	831
28	28	784	704	851	999	1677	1814	1951	595	744	893
30	30	900	808	977	1147	1925	2082	2240	684	855	1026
32	32	1024	919	1112	1305	2190	2369	2548	778	972	1167
33	33	1089	977	1183	1388	2329	2520	2710	827	1034	1241
34	34	1154	1036	1253	1471	2468	2670	2872	877	1096	1315
36	36	1296	1163	1408	1652	2772	2999	3225	985	1231	1477

LOAD ON COLUMN BARS IN KIPS.

Round Mild Steel Bars. $C_l = 18,000$ p.s.i.

PART II.

TABLE 2.

Bar Size Rounds	For 760 p.s.i. Concrete Stress. Load on Bars 17240 $A_c \div$ 1000									
	Number of Bars									
	4	6	8	10	12	14	16	18	20	22
$\frac{1}{2}''$	13	20	27	33	40	47	54	60	67	94
$\frac{5}{8}''$	21	31	42	53	63	74	84	95	105	116
$\frac{3}{4}''$	30	45	60	76	91	106	121	137	152	167
$\frac{7}{8}''$	41	62	83	103	124	145	165	186	207	228
$1''$	54	81	108	135	162	189	216	243	270	297
$1\frac{1}{8}''$	68	102	137	171	205	240	274	308	342	376
$1\frac{1}{4}''$	84	126	169	211	254	296	338	380	423	465
$1\frac{3}{8}''$	102	153	204	256	307	358	409	460	512	563
$1\frac{1}{2}''$	121	182	243	304	365	426	487	548	609	670
$1\frac{5}{8}''$	143	214	286	357	429	500	572	643	715	786
$1\frac{3}{4}''$	165	248	331	414	497	580	663	746	829	912
$1\frac{7}{8}''$	190	285	380	476	570	666	761	856	952	1047
$2''$	216	325	433	541	650	758	866	974	1083	1191

Bar Size Rounds	For 950 p.s.i. Concrete Stress. Load on Bars 17050 $A_c \div$ 1000.									
$\frac{1}{2}''$	13	20	26	33	40	46	53	60	67	93
$\frac{5}{8}''$	21	31	41	52	62	73	83	94	104	115
$\frac{3}{4}''$	30	45	60	75	90	105	120	135	150	165
$\frac{7}{8}''$	41	61	82	102	123	143	164	184	205	225
$1''$	53	80	107	133	160	187	214	241	267	294
$1\frac{1}{8}''$	67	101	135	169	203	237	271	305	339	372
$1\frac{1}{4}''$	83	125	167	209	251	293	334	376	418	460
$1\frac{3}{8}''$	101	152	202	253	303	354	405	455	506	556
$1\frac{1}{2}''$	120	180	241	301	361	421	482	542	602	662
$1\frac{5}{8}''$	141	212	282	353	424	495	565	636	707	777
$1\frac{3}{4}''$	164	246	328	410	492	574	656	738	820	902
$1\frac{7}{8}''$	188	282	376	470	564	659	753	847	941	1035
$2''$	214	321	428	535	642	749	857	964	1071	1178

LOAD ON COLUMN BARS IN KIPS.

Round Mild Steel Bars. $C_1 = 18,000$ p.s.i.

PART II.

TABLE 2—*Continued.*

Bar Size Rounds	For 1140 p.s.i. Concrete Stress. Load on Bars $16860\ A_c \div 1000$									
	Number of Bars									
	4	6	8	10	12	14	16	18	20	22
$1/_2''$	13	19	26	33	39	46	53	59	66	92
$5/_8''$	20	31	41	51	62	72	82	93	103	113
$3/_4''$	29	44	59	74	89	104	119	134	149	163
$7/_8''$	40	60	81	101	121	142	162	182	202	222
$1''$	53	79	105	132	158	185	212	238	264	291
$1^1/_8''$	67	100	134	167	201	234	268	301	335	368
$1^1/_4''$	82	124	165	206	248	289	331	372	413	455
$1^3/_8''$	100	150	200	250	300	350	400	450	500	550
$1^1/_2''$	119	178	238	298	357	417	476	536	595	655
$1^5/_8''$	140	209	279	349	419	489	559	629	699	769
$1^3/_4''$	162	243	324	405	486	567	648	729	811	892
$1^7/_8''$	186	279	372	465	558	651	744	838	931	1024
$2''$	212	317	423	529	635	741	847	953	1059	1165

LOAD ON COLUMN BARS IN KIPS.
Square Mild Steel Bars. $C_l = 18,000$ p.s.i.
PART II.
TABLE 3.

Bar Size Squares	For 760 p.s.i. Concrete Stress. Load on Bars = 17240 $A_c \div 1000$				
	Number of Bars.				
	4	6	8	10	12
$\frac{1}{2}''$	17	25	34	43	51
$\frac{5}{8}''$	26	40	53	67	80
$\frac{3}{4}''$	38	58	77	96	116
$\frac{7}{8}''$	52	79	105	132	158
$1''$	69	103	138	172	206
$1\frac{1}{8}''$	87	130	174	218	261
$1\frac{1}{4}''$	107	161	215	269	323

Bar Size Squares	For 950 p.s.i. Concrete Stress. Load on Bars = 17050 $A_c \div 1000$.				
$\frac{1}{2}''$	17	25	34	42	51
$\frac{5}{8}''$	26	39	53	66	80
$\frac{3}{4}''$	38	57	76	95	115
$\frac{7}{8}''$	52	78	104	130	156
$1''$	68	102	136	170	204
$1\frac{1}{8}''$	86	129	172	215	259
$1\frac{1}{4}''$	106	160	213	266	319

Bar Size Squares	For 1140 p.s.i. Concrete Stress. Load on Bars = 16860 $A_c \div 1000$.				
$\frac{1}{2}''$	16	25	33	42	50
$\frac{5}{8}''$	26	39	52	66	79
$\frac{3}{4}''$	38	57	75	94	113
$\frac{7}{8}''$	51	77	103	129	155
$1''$	67	101	134	168	202
$1\frac{1}{8}''$	85	128	170	213	255
$1\frac{1}{4}''$	105	158	210	263	316

LOAD ON COLUMN BARS IN KIPS.
Square Twisted Bars. $C_l = 20{,}000$ p.s.i.
PART II.
TABLE 4.

Bar Size Square Twisted	For 760 p.s.i. Concrete Stress. Load on Bars = 19240 $A_c \div 1{,}000$.				
	Number of Bars.				
	4	6	8	10	12
$\frac{1}{2}''$	19	28	38	48	57
$\frac{5}{8}''$	30	45	60	75	90
$\frac{3}{4}''$	43	65	86	108	129
$\frac{7}{8}''$	58	88	117	147	176
$1''$	77	115	154	192	230
$1\frac{1}{8}''$	97	146	194	243	291
$1\frac{1}{4}''$	120	180	240	300	360
For 950 p.s.i. Concrete Stress. Load on Bars = 19050 $A_c \div 1000$.					
$\frac{1}{2}''$	19	28	38	47	57
$\frac{5}{8}''$	29	44	59	74	89
$\frac{3}{4}''$	42	64	85	107	128
$\frac{7}{8}''$	58	87	116	146	175
$1''$	76	114	152	190	228
$1\frac{1}{8}''$	96	144	192	241	288
$1\frac{1}{4}''$	119	178	238	297	357
For 1140 p.s.i. Concrete Stress. Load on Bars = 18860 $A_c \div 1000$.					
$\frac{1}{2}''$	18	28	37	47	56
$\frac{5}{8}''$	29	44	58	73	88
$\frac{3}{4}''$	42	63	84	106	127
$\frac{7}{8}''$	57	86	115	144	173
$1''$	75	113	150	188	226
$1\frac{1}{8}''$	95	143	190	238	285
$1\frac{1}{4}''$	117	177	235	294	353

LOAD ON COLUMN BARS IN KIPS.

"Tentor" Bars. $C_l = 20,000$ p.s.i.

PART II.

TABLE 5.

Bar Size "Tentor"	For 760 p.s.i. Concrete Stress. Load on Bars = 19240 $A_c \div 1000$.				
	Number of Bars.				
	4	6	8	10	12
$\frac{1}{2}''$	15	22	30	37	45
$\frac{5}{8}''$	23	35	47	59	70
$\frac{3}{4}''$	34	51	68	85	102
$\frac{7}{8}''$	46	69	92	115	139
$1''$	60	90	120	151	181

Bar Size	For 950 p.s.i. Concrete Stress. Load on Bars = 19050 $A_c \div 1000$.				
$\frac{1}{2}''$	15	22	30	37	45
$\frac{5}{8}''$	23	35	46	58	70
$\frac{3}{4}''$	33	50	67	84	101
$\frac{7}{8}''$	46	68	91	114	137
$1''$	59	89	119	149	179

Bar Size	For 1140 p.s.i. Concrete Stress. Load on Bars = 18860 $A_c \div 1000$.				
$\frac{1}{2}''$	14	22	29	37	44
$\frac{5}{8}''$	23	34	46	58	69
$\frac{3}{4}''$	33	50	66	83	100
$\frac{7}{8}''$	45	68	90	113	136
$1''$	59	88	118	148	177

Tables 1-5 adapted from the *Reinforced Concrete Design Handbook* of the American Concrete Institute.

AREAS OF COLUMN BARS (Sq. in.).
TABLE 6.

Bar Size Rounds	Rounds Mild Steel or "Tentor" Number of Bars									
	4	6	8	10	12	14	16	18	20	22
$1/2''$	0·79	1·18	1·57	1·96	2·35	2·75	3·14	3·53	3·93	5·47
$5/8''$	1·23	1·84	2·45	3·07	3·68	4·30	4·91	5·52	6·14	6·75
$3/4''$	1·77	2·65	3·53	4·42	5·30	6·19	7·07	7·95	8·84	9·72
$7/8''$	2·40	3·61	4·81	6·01	7·22	8·42	9·62	10·82	12·03	13·22
$1''$	3·14	4·71	6·28	7·85	9·42	11·00	12·57	14·14	15·71	17·27
$1 1/8''$	3·98	5·96	7·95	9·94	11·93	13·92	15·90	17·89	19·88	21·86
$1 1/4''$	4·91	7·36	9·82	12·27	14·73	17·18	19·64	22·09	24·54	26·99
$1 3/8''$	5·94	8·91	11·88	14·85	17·82	20·79	23·76	26·73	29·70	32·66
$1 1/2''$	7·07	10·60	14·14	17·67	21·21	24·74	28·27	31·81	35·34	38·87
$1 5/8''$	8·30	12·44	16·59	20·74	24·89	29·04	33·18	37·33	41·48	45·62
$1 3/4''$	9·62	14·43	19·24	24·05	28·86	33·67	38·48	43·29	48·10	52·92
$1 7/8''$	11·04	16·57	22·09	27·61	33·13	38·65	44·18	49·70	55·22	60·74
$2''$	12·57	18·85	25·14	31·42	37·70	43·98	50·26	56·54	62·82	69·12

Bar Size Squares	Squares Plain or Twisted Number of Bars									
	4	6	8	10	12	14	16	18	20	22
$1/2''$	1·00	1·50	2·00	2·50	3·00	3·50	4·00	4·50	5·00	5·50
$5/8''$	1·56	2·34	3·12	3·91	4·69	5·47	6·25	7·03	7·81	8·60
$3/4''$	2·25	3·38	4·50	5·62	6·75	7·87	9·00	10·12	11·25	12·38
$7/8''$	3·06	4·59	6·12	7·66	9·19	10·72	12·25	13·78	15·31	16·84
$1''$	4·00	6·00	8·00	10·00	12·00	14·00	16·00	18·00	20·00	22·00
$1 1/8''$	5·06	7·59	10·12	12·66	15·19	17·72	20·25	22·78	25·31	27·84
$1 1/4''$	6·25	9·38	12·50	15·62	18·75	21·88	25·00	28·13	31·25	34·38

SQUARE TIED COLUMNS. C.P. 114 (1948).
SAFE AXIAL LOADS IN KIPS (1,000 lbs.).
Mild Steel. $C_l = 18,000$ p.s.i.
TABLE 7.

Column Size in.	% Vertical Bars	NORMAL GRADE CONCRETE			A_c Sq. in.
		$1:2:4$ $c = 760$	$1:1\frac{1}{2}:3$ $c = 950$	$1:1:2$ $c = 1140$	
8×8	1	59	71	83	0·64
	2	70	82	94	1·28
	3	81	93	105	1·92
	4	92	104	116	2·56
	5	103	115	127	3·20
	6	114	126	137	3·84
	7	125	137	148	4·48
	8	137	148	159	5·12
9×9	1	75	90	106	0·81
	2	89	104	119	1·62
	3	103	118	133	2·43
	4	117	132	147	3·24
	5	131	146	160	4·05
	6	145	159	174	4·86
	7	159	173	188	5·67
	8	173	187	201	6·48
10×10	1	93	112	130	1·0
	2	110	129	147	2·0
	3	127	146	164	3·0
	4	145	163	181	4·0
	5	162	180	198	5·0
	6	179	197	215	6·0
	7	196	214	232	7·0
	8	214	231	248	8·0

Table 7—*continued.*

Column Size in.	% Vertical Bars	NORMAL GRADE CONCRETE			A_c Sq. in.
		1: 2 : 4 $c = 760$	1 : 1½ : 3 $c = 950$	1 : 1 : 2 $c = 1140$	
11 × 11	1	112	135	158	1·21
	2	133	156	178	2·42
	3	154	176	199	3·63
	4	175	197	219	4·84
	5	196	218	240	6·05
	6	217	238	260	7·26
	7	238	259	280	8·47
	8	258	280	301	9·68
12 × 12	1	134	161	188	1·44
	2	159	186	212	2·88
	3	184	210	237	4·32
	4	208	235	261	5·76
	5	233	259	285	7·20
	6	258	284	309	8·64
	7	283	308	334	10·08
	8	308	333	358	11·52
13 × 13	1	157	189	221	1·69
	2	186	218	249	3·38
	3	215	247	278	5·07
	4	245	275	306	6·76
	5	274	304	335	8·45
	6	303	333	363	10·14
	7	332	362	392	11·83
	8	361	391	420	13·52

Table 7—*continued*.

Column Size in.	% Vertical Bars	NORMAL GRADE CONCRETE			A_c Sq. in.
		1 : 2 : 4 $c = 760$	1 : 1½ : 3 $c = 950$	1 : 1 : 2 $c = 1140$	
14 × 14	1	182	219	256	1·96
	2	216	253	289	3·92
	3	250	286	322	5·88
	4	284	319	355	7·84
	5	318	353	388	9·80
	6	351	386	421	11·76
	7	385	420	454	13·72
	8	419	453	487	15·68
15 × 15	1	209	252	294	2·25
	2	248	290	332	4·50
	3	287	328	370	6·75
	4	326	367	408	9·00
	5	365	405	446	11·25
	6	403	444	484	13·50
	7	442	482	522	15·75
	8	481	520	560	18·00
16 × 16	1	238	286	335	2·56
	2	282	330	378	5·12
	3	327	374	421	7·68
	4	371	417	464	10·24
	5	415	461	507	12·80
	6	459	505	550	15·36
	7	503	548	594	17·92
	8	547	592	637	20·48

Table 7—*continued.*

Column Size in.	% Vertical Bars	Normal Grade Concrete			A_c Sq. in.
		1 : 2 : 4 $c = 760$	1 : 1½ : 3 $c = 950$	1 : 1 : 2 $c = 1140$	
17 × 17	1	269	323	378	2·89
	2	319	373	427	5·78
	3	369	422	475	8·67
	4	419	471	524	11·56
	5	468	521	573	14·45
	6	518	570	621	17·34
	7	568	619	670	20·23
	8	618	668	719	23·12
18 × 18	1	302	363	424	3·24
	2	358	418	478	6·48
	3	413	473	533	9·72
	4	469	528	588	12·96
	5	525	584	642	16·20
	6	581	639	697	19·44
	7	637	694	751	22·68
	8	693	749	806	25·92
19 × 19	1	336	404	472	3·61
	2	398	466	533	7·22
	3	461	527	594	10·83
	4	523	589	655	14·44
	5	585	650	715	18·05
	6	647	712	776	21·66
	7	710	773	837	25·27
	8	772	835	898	28·88

Table 7—*continued.*

Column Size in.	% Vertical Bars	NORMAL GRADE CONCRETE			A_c Sq. in.
		1 : 2 : 4 $c = 760$	1 : 1½ : 3 $c = 950$	1 : 1 : 2 $c = 1140$	
20 × 20	1	373	448	523	4·0
	2	442	516	590	8·0
	3	510	584	658	12·0
	4	579	652	725	16·0
	5	648	721	793	20·0
	6	717	789	860	24·0
	7	786	857	928	28·0
	8	855	925	995	32·0
21 × 21	1	411	494	577	4·41
	2	487	569	651	8·82
	3	563	644	725	13·23
	4	639	719	800	17·64
	5	715	795	874	22·05
	6	791	870	948	26·46
	7	867	945	1023	30·87
	8	943	1020	1097	35·28
22 × 22	1	451	542	633	4·84
	2	534	624	715	9·68
	3	618	707	796	14·52
	4	701	789	878	19·36
	5	785	872	959	24·20
	6	818	955	1041	29·04
	7	952	1037	1123	33·88
	8	1035	1120	1204	38·72

Table 7—*continued*.

Column Size in.	% Vertical Bars	Normal Grade Concrete			A_c Sq. in.
		$1:2:4$ $c = 760$	$1:1\frac{1}{2}:3$ $c = 950$	$1:1:2$ $c = 1140$	
23×23	1	493	592	692	5·29
	2	584	682	781	10·58
	3	675	773	870	15·87
	4	766	863	959	21·16
	5	858	953	1049	26·45
	6	949	1043	1138	31·74
	7	1040	1133	1227	37·03
	8	1131	1224	1316	42·32
24×24	1	537	645	753	5·76
	2	636	743	850	11·52
	3	735	841	948	17·28
	4	835	940	1045	23·04
	5	934	1038	1142	28·80
	6	1033	1136	1239	34·56
	7	1132	1234	1336	40·32
	8	1232	1332	1433	46·08
25×25	1	582	700	817	6·25
	2	690	806	923	12·50
	3	798	913	1028	18·75
	4	906	1020	1134	25·00
	5	1013	1126	1239	31·25
	6	1121	1233	1344	37·50
	7	1229	1339	1450	43·75
	8	1337	1446	1555	50·00

Table 7—*continued*.

Column Size in.	% Vertical Bars	NORMAL GRADE CONCRETE			A_c Sq. in.
		1 : 2 : 4 $c = 760$	1 : 1½ : 3 $c = 950$	1 : 1 : 2 $c = 1140$	
26 × 26	1	630	757	884	6·76
	2	746	872	998	13·52
	3	863	988	1112	20·28
	4	980	1103	1226	27·04
	5	1096	1218	1340	33·80
	6	1213	1333	1454	40·56
	7	1329	1449	1568	47·32
	8	1446	1564	1682	54·08
28 × 28	1	731	878	1026	7·84
	2	866	1012	1158	15·68
	3	1001	1145	1290	23·52
	4	1136	1279	1422	31·36
	5	1271	1413	1554	39·20
	6	1406	1546	1686	47·04
	7	1542	1680	1819	54·88
	8	1677	1814	1951	62·72
30 × 30	1	839	1008	1177	9·0
	2	994	1162	1329	18·0
	3	1149	1315	1481	27·0
	4	1304	1468	1633	36·0
	5	1459	1622	1784	45·0
	6	1615	1775	1936	54·0
	7	1770	1929	2088	63·0
	8	1925	2082	2240	72·0

Table 7—*continued.*

Column Size in.	% Vertical Bars	Normal Grade Concrete			A_c Sq. in.
		1 : 2 : 4 $c = 760$	1 : 1½ : 3 $c = 950$	1 : 1 : 2 $c = 1140$	
32 × 32	1	954	1147	1340	10·24
	2	1131	1322	1512	20·48
	3	1307	1496	1685	30·72
	4	1484	1671	1858	40·96
	5	1661	1845	2030	51·20
	6	1837	2020	2203	61·44
	7	2014	2195	2375	71·68
	8	2190	2369	2548	81·92
34 × 34	1	1076	1293	1510	11·54
	2	1275	1489	1704	23·08
	3	1473	1686	1899	34·62
	4	1672	1883	2093	46·16
	5	1871	2080	2288	57·70
	6	2070	2276	2483	69·24
	7	2269	2473	2677	80·78
	8	2468	2670	2872	92·32
36 × 36	1	1208	1452	1696	12·96
	2	1431	1673	1914	25·92
	3	1655	1894	2133	38·88
	4	1878	2115	2351	51·84
	5	2102	2336	2570	64·80
	6	2325	2557	2788	77·76
	7	2549	2778	3007	90·72
	8	2772	2999	3225	103·68
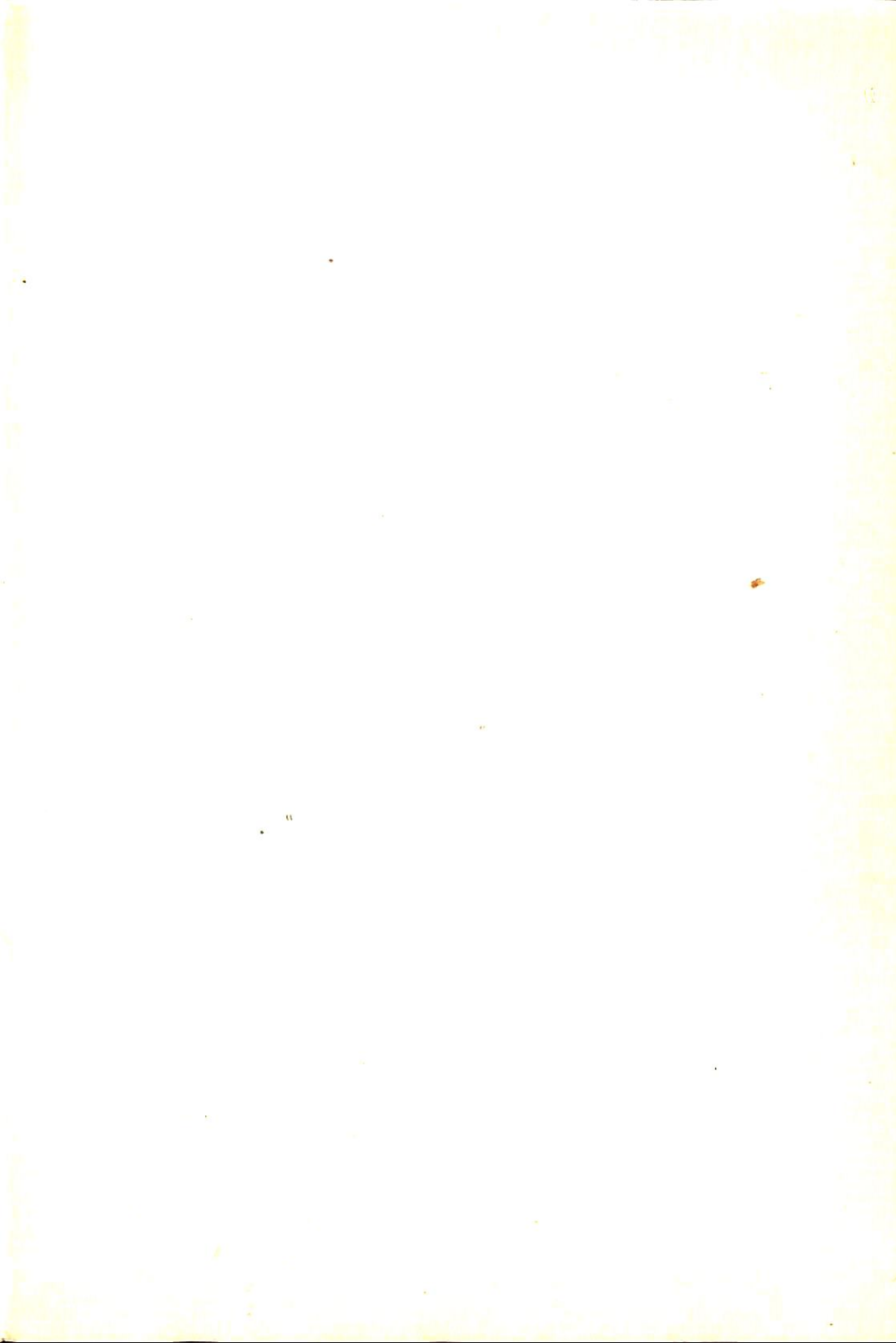
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